1. Title of the project

Double-gate light-emitting field-effect transistor as tool for investigating bulk heterojunctions

2. Aplicant(s)

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5. Abstract

We propose to study a novel class of devices that are simultaneously light emitting and switching elements – light emitting field-effect transistors. The structure of such a device resembles that of the field effect transistor but light can be emitted out of its channel under certain operation regimes.

We suggest to fabricate *double-gate* light emitting field-effect transistor. This architecture will allow new opportunities to study excitonic processes, charge transport and charge-exciton interactions in the transistor's channel. As an active layer we will use the blend of two materials, called bulk heteojunction. It will be designed such that one of the materials will have electron-conducting and another hole-conducting properties. This architecture allows to achieve the ambipolar transport and the light emission under certain conditions.

The purpose of our research is to study the *dynamics* of processes that happen in the ambipolar channel of the double- and single-gate devices *under operation.* We will use spectroscopic tools such as SNOM, confocal microscopy and time resolved spectroscopy for that.

We believe that these devices could open a new area in optoelectronics and new possibilities to study bulk heterojunctions.

6. Duration of the project

4 years, starting from September 2007

7. Personnel

The personnel working on this project are all part of the research group *Physics of Organic Semiconductors*, part of the research cluster *Molecular Electronics* of *the Materials Science Centre*^{Plus}*:*

Prof. Dr. Ir. P.W.M. Blom (Professor / Leader of the research group)
Dr. Maria Antonietta Loi (Assistant Professor / Project Leader)
O. Mikhnenko (Applicant / PhD Student)
J. Harkema (Technician)
F. van der Horst (Technician)

8. Cost-estimates

8.1 Personnel positions

One 'onderzoeker in opleiding' position for four years.

8.2 Running Budget

15 k€/year

8.3 Equipment

No equipment is requested.

8.4 Other support

The project is part of a larger research programme of the MSCplus. Involved personnel described above is employed via the MSCplus or associated research programmes.

8.5 Budget summary (in k€)

The expenses are summarized in the following table:

	2007	2008	2009	2010	2011	Total
Positions:						
PhD Students	1	1	1	1	1	
Postdocs	-	-	-	-	-	
Technicians	-	-	-	-	-	
Guests	-	-	-	-	-	
Personnel Costs	13	38	43	46	32	172
Running Budget	7.5	15	15	15	7.5	60
Equipment	-	-	-	-	-	-
Total	20.5	53	58	61	39.5	232

9. Research programme

9a. Introduction

Organic semiconductors are a very important research topic in materials science. Compared to inorganic materials they have many advantages such as low cost, easy processibility, flexibility, possibility of chemical tuning, low weight etc. However, these materials usually suffer from problems related to low purity and mobility. A number of different devices like organic light emitting diode (LED), photovoltaic cell, field-effect transistor (FET), organic memory etc. were designed using organic semiconductors and some of them are commercially available now.

Flexible active matrix displays are of high technological interest. Every pixel of such a display is composed by a LED and a transistor. Organic transistors usually have low performances that are not sufficient for such applications. That is why for this application the transistors are usually made of amorphous or polycrystalline silicon [1]. Only recently fully organic active matrix displays were reported [2]. This approach requires the integration of two devices into a single pixel, involving technological complications and high costs. Lately a new device which combines light emission and transistor functionalities was discovered [3]. Such a device was named organic Light Emitting field-effect Transistor (LET). The structure of this device resembles a usual field-effect transistor, but light is emitted in the channel when specific active media are used and under particular operation regimes.

In addition to active matrix displays, LETs can be used in different optoelectronics applications, in optical communication devices and potentially to achieve electrically pumped lasers [4]. Besides the technological use LETs are interesting as a tool to study fundamental properties of organic materials. They are excellent structures to investigate excitations' lifetimes under device operation and allow probing recombination and emission through direct observation.

9b. Research question(s)

Both electrons and holes are needed in the channel of FET for exciton formation and subsequent light emission. Thus the active layer should support ambipolar transport. Despite in theory organic materials are expected to conduct both electrons and holes, in practice they usually behave as either electron or hole conductors. Very few organic materials are known to have intrinsic ambipolar transport but their mobilities are limited to $10^{-5} – 10^{-4}$ $cm^2V^{-1}s^{-1}$ [5,6].

The first reported organic light-emitting field-effect transistor had unipolar hole conducting channel [3]. The light emission was observed near the drain electrode, where the electrons are injected. Due to the vicinity of the exciton recombination region to the drain electrode additional mechanisms of radiationless decay are introduced such as energy transfer to the metal electrode, quenching due to charge accumulation or other effects that reduce emission efficiency. Similar problems are encountered by devices using a vertical topology as organic LEDs [7]. In these devices the problem is partially solved by technological complications such as extra layers deposition (see for instance

[8]). In ambipolar LET it is possible to limit these parasitic processes by moving the light emitting zone far from the metal contacts by modulating the gate voltage.

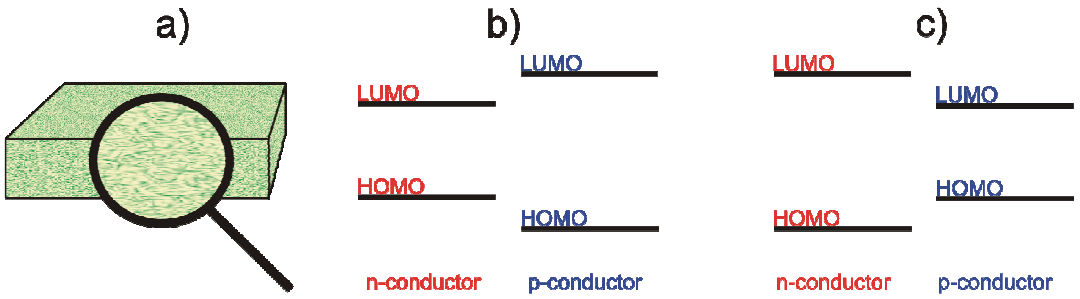

Fig. 1. *The two materials in the bulk heterojunction are schematically depicted with different colors (a); relative position of the LUMOs and the HOMOs of the components in bulk heterojunction: (b) the light emitting material is the n-conductor and (c) the light emitting material is the p-conductor.*

Consequently ambipolar transport is a desirable property of the active medium of LET. But due to the limited number of intrinsically ambipolar materials alternative approaches have been developed [9]. Ambipolar transport is reported in tandem heterostructures [10] and bulk heterojunctions (i.e. a three dimensional heterojunction) [11]. In both "hetero-" approaches two different materials are used: one conducting electrons and another holes.

The high interest for bulk heterojunctions is also emphasized by its wide applications in other devices like solar cells [12] and LEDs [13]. The most important characteristic of bulk heterojunction is the presence of large three dimensional interface between the intermixed phases (Fig. 1a). The interactions between the phases depend on the relative concentrations of the components, the process used for blend preparation and the morphology of the interface. All these parameters can influence the physical properties of bulk heterojunctions making of it a challenging object for research.

Despite bulk heterojunctions are highly disordered systems, they sometimes exhibit higher ambipolar mobilities compared to neat materials [14]. The study of charge transport in conjugation with morphology mapping can shine light on the importance of the order in bulk heterojunctions.

In this project we will concentrate on bulk heterojunction as an active layer for LETs. In these devices the gate electrode has a very important role: two extreme cases are the electrons (under application of high positive gate voltage) or holes (high negative gate voltage) accumulation regimes. Ambipolar transport can be achieved in the intermediate range of gate voltage. In this regime electro luminescence is possible. The electro luminescence appears to be localized in the channel and its position can be controlled by the gate voltage [5,6,15]. However the physics of formation of such light emission zone is not clear and the efficiencies of reported devices are not high enough for practical applications.

Due to the importance of the gate field for the functioning of these devices, we suggest to fabricate a double gate LETs. The device is schematically depicted in Fig. 2. The two gates are separated from the ambipolar active layer by thin films of dielectric.

The second gate introduces extra working regimes for channel operation and makes possible a higher level of control of the electrical field inside the channel. Such architecture could be also interesting for electrically pumped laser design [4].

The **aims of the project** are to fabricate double gate LETs and to study physical processes that happen in the bulk heterojunction under influence of the double gate. We will focus on charge transport, exciton formation and its quenching/recombination. With this knowledge we will consider the possibility to fabricate LETs with lower operational voltages and with improved electroluminescence efficiency.

9c. Method/Approach

The selection of the materials for the fabrication of the bulk heterojunction is based on the following physical arguments. In order to achieve ambipolar transport one of the materials should have hole conducting properties, and the other one electron conducting properties. Since we want to favour exciton recombination, appropriate bandgaps should be selected to favour exciton formation on one of the components. This can be achieved when the HOMO and the LUMO of the light emitting material lies within the bandgap of the other material (Fig. 1b,c) under the condition that there is no back transfer of one of the charges. Moreover, radiative decay should be favourable in the lower energy bandgap material. As first materials we will use N,N'-ditridecylperylene-3,4,9,10-tetracarboxylic-diimide (P13) and α-sexithiophene (T6) that match these requirements [15]. The preparation of bulk heterojunctions will be done by co-evaporation technique in high vacuum. In such a way insoluble blend can be fabricated, that will allow to use spincoating technique for the deposition of the second gate on top of the device.

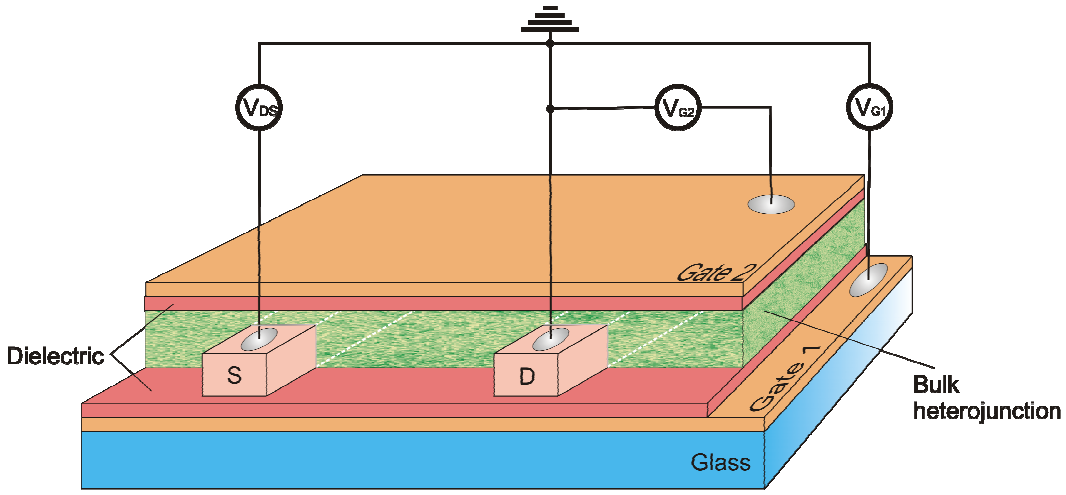

Fig. 2. *Double-gate light-emitting field-effect transistor is depicted schematically.*

Ohmic contacts *(source - active layer – drain)* are required to get efficient charge injection in the channel. Therefore drain (source) metal should have high (low) workfunction for hole (electron) injection. Gold and ITO (indium tin oxide) are good candidates as hole injection contact. Low workfunction metals are usually reactive and are difficult to process. However, electron injection was reported from gold electrodes into some materials [11,15]. Therefore a few metals should be tried and the final

selection will be made based on the consideration of the ability to inject both charges into the bulk heterojunction, processibility and stability properties.

The bulk heterojunction under influence of electrical field will be studied with optical techniques in this project. Steady state and time-resolved photoluminescence as well as photoinduced absorption techniques will be used. Such techniques will give us information about exciton formation/quenching processes and charge-exciton interactions. Moreover, scanning near-field optical microscopy (SNOM), confocal microscopy and atomic force microscopy (AFM) will be used to study the morphology of bulk heterojunctions and its influence on the physical properties. Spatially resolved photoluminescence measurements (SNOM, confocal microscopy) will be performed in both single and double gate LETs *under operation*. This will allow us to study the interaction of the excitons with the charges in the channel.

In order to do optical measurement transparent gate electrodes are needed. We propose to use glass substrate with ITO film as the first gate electrode (see Fig. 2). From the glass side confocal microscopy measurements can be performed in order to do spatially resolved measurements. As the second gate electrode several different approaches will be tried such as spincoating PEDOT:PSS thin film or depositing thin transparent layer of metal.

9d. Innovation

We propose to fabricate double-gate light-emitting field-effect transistor using bulk heterojunction as the active layer. This novel device will allow new opportunities to study the physical properties of the bulk heterojunction. In our research we will use spectroscopic tools such as SNOM, confocal microscopy and time resolved spectroscopy to study the *dynamics* of processes that happen in the channel of the device *under operation.* Moreover the study of dependence of charge transport on morphology will give information about the importance of the order in bulk heterojunction.

The fundamental knowledge gained on functioning of double-gate light-emitting field-effect transistor will be used to improve the electro luminescent efficiency of this new class of devices.

9e. Relevance for science, technology or society

Our project includes both technological and fundamental investigations. From one hand we propose a new device architecture – double-gate light-emitting field-effect transistor – that is potentially more efficient than single gate LET. From the other hand the extra gate electrode enables new opportunities for probing charge transport and exciton evolution in bulk heterojunctions.

The development of the light-emitting field-effect transistors will lead to applications in rollable active matrix displays, making possible the development of the next generation of mobile communications.

9f. Literature references

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